Energies **2014**, *7*, 8508-8534; doi:10.3390/en7128508

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Article

Wind Energy Study and Energy Cost of Wind Electricity Generation in Nigeria: Past and Recent Results and a Case Study for South West Nigeria

Oluseyi O. Ajayi [1], Richard O. Fagbenle [2], James Katende [3], Julius M. Ndambuki [4], David O. Omole [4,5,*] and Adekunle A. Badejo [4]

[1] Mechanical Engineering Department, Covenant University, Private Mail Bag 1023, Ota 112101, Nigeria; E-Mail: oluseyi.ajayi@covenantuniversity.edu.ng or seyi_ajayi@yahoo.com.au
[2] Mechanical Engineering Department, Obafemi Awolowo University, Ile-Ife 220282, Nigeria; E-Mail: ro.fagbenle@mail.ui.edu.ng or layifagbenle@yahoo.com
[3] College of Engineering and Technology, Botswana International University of Science and Technology, Gaborone 0000, Botswana; E-Mail: sempa54@gmail.com
[4] Department of Civil Engineering, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa; E-Mails: NdambukiJM@tut.ac.za (J.M.N.); BadejoAA@tut.ac.za (A.A.B.)
[5] Civil Engineering Department, Covenant University, Private Mail Bag 1023, Ota 112101, Nigeria

* Author to whom correspondence should be addressed; E-Mail: domole@covenantuniversity.com; Tel.: +27-12-382-6493.

External Editor: Frede Blaabjerg

Received: 26 September 2014; in revised form: 11 November 2014 / Accepted: 24 November 2014 / Published: 22 December 2014

Abstract: The study assessed the wind energy potential of ten selected sites in the south western region of Nigeria and carried out a cost benefit analysis of wind power generation at those sites. Twenty four years' (1987 to 2010) wind speed data at 10 m height obtained from the Nigerian meteorological agency were employed to classify the sites wind profiles for electricity generation. The energy cost analysis of generating wind electricity from the sites was also carried out. The outcome showed that sites in Lagos and Oyo States were adequately suited for large scale generation with average wind speeds ranged between 2.9 and 5.8 m/s. Those from other sites may be suitable for small scale generation or as wind farms, with several small turbines connected together, to generate large enough wind power. The turbine matching results shows that turbines cut-in and rated wind speeds of between 2.0 and 3.0 m/s, and between 10 and 12.0 m/s respectively will be very suited to all the sites, particularly those in locations outside Lagos and Oyo States. The energy cost analysis shows that generation cost can be as low as 0.02 €/kWh and as high as 5.03/kWh, depending on the turbine model employed.

Keywords: wind power; energy cost; Weibull; South West Nigeria; turbine matching

1. Introduction

Energy is one of the major tools of development. Its availability has a great effect on the socio-economic make up of a place, while its variability can lead to fluctuations in the population [1]. The performance of the millennium development goals has over the years has hinged on adequate supplies of modern energy, of which electricity is a key example. Major sources of electricity production are fossil fuel, nuclear reactors, and large and small scale hydroelectric generation. While electricity from hydropower plant is widely acknowledged as environmentally friendly, those from fossil fuels and nuclear power have associated environmental limitations. This is because of the harmful effects of their by-products [1,2]. It is reported that energy production from fossil sources (both in the form of electricity and heating) is one of the major sources of anthropogenic emissions of CO_2 and other greenhouse gases. This has led to the need for ways to create a balance between sustainable socio-economic development and energy security.

Adopting renewable energy resources for electricity production and other energy needs has become a notable objective globally. While countries have started to look at ways of harnessing the abundant environmentally friendly renewable resources, some others have already proved it and are extending their generation capacities. China, United States, Germany, Spain, India are some examples of countries who have annual installed wind power capacities in the regions of some Giga-Watt (GW) of electricity [2,3].

The African continent, though improving in generation capacities, represents the least developed in terms of installed wind power and wind electricity adoption. North Africa, with Egypt (550 MW) and Morocco (286 MW) leads the way. Tunisia (54 MW), South Africa (10 MW) and Kenya are other promising countries. Moreover, projections reveal that in the near future wind power capacities up to few GW will be achieved in places like Egypt, Morocco and South Africa. In sub-Saharan Africa, particularly the West African region, no country has yet generated grid electricity from wind despite the identified opportunities [4].

The challenges of wind energy project development in West Africa may however be linked to inadequate measurements, incomplete assessment studies and/or improper wind classification of the countries in the region. This is partly due to the fact that wind resources are site specific. Therefore, in order to properly classify a country's wind profile, assessment of as many sites will be required. Nigeria's wind profile assessment has gone through various developmental stages. Various policy issues have been generated with the government demonstrating the intention to generate electricity from wind [3,4].

1.1. Wind Profile Characteristics of Nigeria: Review of Some Previous and Recent Results

Various initiatives, both from governments and researchers exist [5,6]. The characterization of Nigeria's wind profile started way back in the mid-nineties. Fagbenle *et al.* [7] summarized the earliest studies on wind energy in Nigeria to include works by Adejokun [8], Fagbenle *et al.* [9] and Ojosu and Salawu [10,11]. Adejokun [8] explained the wind speed distribution across the seasons. Fagbenle *et al.* [9] studied the wind power potential of Nigeria and found that a modal class of about 3.0 m/s characterised the 1951 to 1960 surface wind data at 10 m height from twelve meteorological stations. It also showed that mean wind speeds in the North were twice as high as those of the South, while the high-altitude Jos station in Plateau State had the highest mean wind speed of about 3.6 m/s. Ojosu and Salawu [10,11] analysed annual average wind data from 22 meteorological stations for the period 1951–1975. They concluded that the high-latitude Sokoto station was the windiest, with a monthly average wind speed of 5.12 m/s in June and an annual mean of 3.92 m/s. The report also showed that the middle belt and the southern parts had wind speed values of at most 2.0 m/s.

Other studies include that of Adekoya and Adewale [12], who analyzed wind speed data of 30 stations in Nigeria and determined the annual mean wind speeds and power flux densities to vary from 1.5 to 4.1 m/s and 5.7 to 22.5 W/m^2, respectively. Fagbenle and Karayiannis [13] on the other hand, did an analysis of 10-years' wind data from 1979 to 1988. It considered the surface and upper winds as well as the maximum gusts. Asiegbu and Iwuoha [14] studied the wind resource availability in Umudike, South-East, Nigeria using 10 years (1994–2003) of wind speed data. They found that the economic viability of the site required a hub height of 65 m above the ground with an annual mean wind speed of 5.36 m/s. Fadare [15] carried out a statistical analysis of wind energy potential in Ibadan, using a Weibull distribution function on 10 years (1995–2004) of daily wind speed data. The outcome showed that the city experienced an average wind speed and power density of 2.947 m/s and 15.484 W/m^2. Ogbonnaya *et al.* [16], on the other hand, worked on the prospects of wind energy in Nigeria. Four years' wind data from seven cities (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar) cutting across the different geopolitical zones of the federation were employed. The outcome showed that the annual wind speed at 10 m height for the cities varied from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0–3.9 m/s for high land areas and semi-arid regions. It was also reported that monthly average wind power could be about 50.1 W/m^2 and that it was possible to generate a wind power of 97 MWh/yr from the Sokoto site. Also, Ngala *et al.* [17] did a statistical analysis of the wind energy potential in Maiduguri (Borno State). It employed the Weibull distribution with 10 years (1995–2004) of wind data. Further reports on the various assessment studies both by researchers and government agencies are profiled in Ajayi [5,6].

1.2. Inferences from Previous Studies

Based on the reported results, some inferences can be adduced. These include that Nigeria was classified as having low to moderate wind speed regime, with a magnitude variation between 1.5 and 4.1 m/s. Also, wind power class across the country may be rated to be between 1 and 2, while the northern part of Nigeria experiences better wind speeds than the southern region. More so, most of the assessment studies have focused mostly on the north, possibly because the region is claimed to possess better wind power potential. However, it was noted that studies averaging data for the nation employed a wind speed data band covering between 1951 and 1975. Also the number and geographical spread of the stations employed for the studies placed limitations on the accuracy and applicability of the results. For instance, Fagbenle *et al*. [9] used data from 12 meteorological stations and Ojosu and Salawu [10,11] employed data from 22 meteorological stations to average for the whole country. In the same vein, ECN-UNDP (Energy Commission of Nigeria-United Nations Development of Nigeria) [18] and Lahmeyer [19] based their reports on 12 months average wind speed data for only 10 locations. The spread of the locations were such that three and four stations represented the North West (NW) and North Central (NC) regions and one station each represented North East (NE), South West (SW) and South East (SE), respectively. None represented the South-South (SS) region. Ogbonnaya *et al*. [16] also used 4 years of wind data for seven locations to represent for the nation.

It is worthy of note that wind energy assessments are location specific and hence are limited in terms of accuracy due to the non-linear variability of wind characteristics in space and time. Using a minimal number of locations and sampling points to average for the whole nation may affect the accuracy and utilization of the results. Other limiting factors are the effects of the mechanical turbulences resulting from varying topography and roughness of an area and also thermal turbulences produced by diurnal cycles. Therefore, for efficient exploration of the wind energy potentials of a country, robust nationwide assessment is required.

1.3. Opportunities Presented by Previous Studies

A review of studies on recently measured wind speed bands suggests that the nation actually has better wind speeds than previously reported. For instance, Fadare [20] showed that monthly mean wind speeds measurements covering 1983 to 2003 ranging between 0.9 and 13.1 m/s characterise the nation's wind speed profile against those of earlier measurements. Also, while Ojosu and Salawu [10] reported a wind speed range between 2.16 and 4.84 m/s, and also 2.22 and 3.52 for Potiskum and Maiduguri, respectively, Fagbenle *et al*. [21] reported 3.90 and 5.85 m/s, and 4.35 and 6.33 m/s for the two places, respectively. Such observed differences may be due to increased wind speeds as a result of extensive deforestation across the country [22]. The increase in deforestation can be due to developmental changes that have taken place across the years and also possibly due to biomass burning [3]. Another reason may be due to the effect of climate change on wind speed variability. Scott *et al*. [23] reported that climate change is predicted to cause stronger surface wind speed values across tropical and sub-tropical Africa, with inter-model contrasts being largest in places which include sub-Saharan Africa. Hence, measured wind speed magnitude can be limited by factors such as time period and duration of measurement, and also by the issues of climate change and anthropogenic activities. Given such evidence of increasing wind speeds across previously measured sites, it would be valuable if a reanalysis of new measurements could be carried out. Going by the aforementioned, there is the need to have more recent wind speed measurement results and analyses across the country. This will provide updated information about the true situation of wind power potential of Nigeria and invariably aid in proper decision making as regard the application of wind turbines.

2. Site Characteristics and Wind Speed Data

All available recent assessment results show higher magnitude of wind speeds across all stations studied. For instance, Ajayi *et al*. [24,25] reported the wind power characteristics of the North West (NW) region of Nigeria. The reports demonstrate that monthly mean wind speeds of between 2.6 and 9.8 m/s characterise the wind profiles of the region. It was also reported that modal wind speeds above 4.0 m/s typify the region's wind regime. Further on this, Ahmed *et al*. [26] and Ajayi *et al*. [27] provided reports of wind profile studies of stations in the North Central (NC) region of Nigeria. Average wind speeds of between 2.2 and 10.1 m/s are prevalent in the region. Reports also exist for the North East (NE) region [21].

Like previous studies, most of the recent studies also focused on the northern regions. More therefore needs to be done to expose the wind profile characteristics of the southern regions of Nigeria. Further to this, such studies will require the use of more recent wind speed databases that are not older than the 1980s and updated to most recent times. Based on this, this study focused on the analyses of wind speed data for 10 stations in the South West region of Nigeria. It employed wind speed data covering the period between 1987 and 2010. Information relating to these stations is given in Table 1 and the geographical location is as displayed in Figure 1. The climatic condition of the studied sites is prevalently of two seasons, the wet and dry ones. The dry periods are dominated by hot, dry, low humidity, and dusty winds that blow from the Sahara towards the Gulf of Guinea between November and March every year.

Figure 1. Map of Africa showing the location and states of the study areas [28].

Table 1. Location information for the Nigeria Meteorological (NIMET) stations.

Serial number	State	Station's location	Latitude (N)	Longitude (E)	Elevation (m)	Air Density (kg/m^3)
1	Lagos	Ikeja	6.35'	3.20'	39.4	1.2205
2	Lagos	Lagos Marine	6.26'	3.25'	2	1.2248
3	Lagos	Lagos Island	6.26'	3.25'	2	1.2248
4	Oyo	Ibadan	7.26'	3.54'	227.2	1.1988
5	Osun	Oshogbo	7.47'	4.29'	302	1.1902
6	Ogun	Abeokuta	7.10'	3.20'	104	1.213
7	Ogun	Ijebu-Ode	6.50'	3.56'	77	1.2161
8	Ondo	Akure	7.17'	5.18'	375	1.1817
9	Ondo	Ondo	7.06'	4.50'	287.3	1.1919
10	Ekiti	Ado Ekiti	7.38'	5.13'	455	1.2020

Although results exist for a site in Ibadan [15], the station's data employed for the study were those obtained from the International Institute of Tropical Agriculture (IITA), Ibadan (latitude 7°3'N, longitude 3°54'E). Those employed for Ibadan in this study were obtained from the Nigeria Meteorological agency (NIMET). The NIMET station in Ibadan is located differently from IITA (about 25 km apart). Thus, analysing data for NIMET station in Ibadan provides information for an additional measuring site in Ibadan.

Wind data for the stations were obtained from NIMET, Oshodi, and Lagos State. The data were those of wind speeds at 10 m height captured with three-cup anemometer generator and covering the periods between 1987 and 2010. The accuracy of the anemometer instrument is ±2%. Graphical presentation of the stations' monthly average and the range of mean measured wind speeds distributions for the stations across the 24 years period are presented in Figures 2 and 3.

Figure 2. 24 years' average monthly wind speeds distributions across the stations.

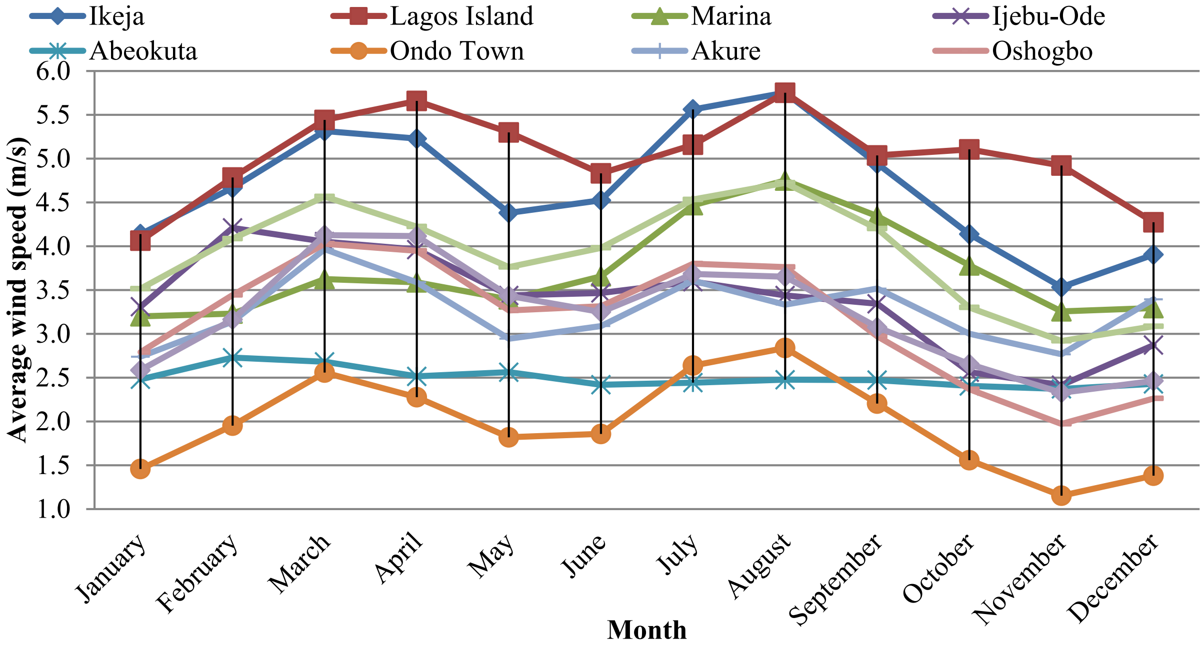
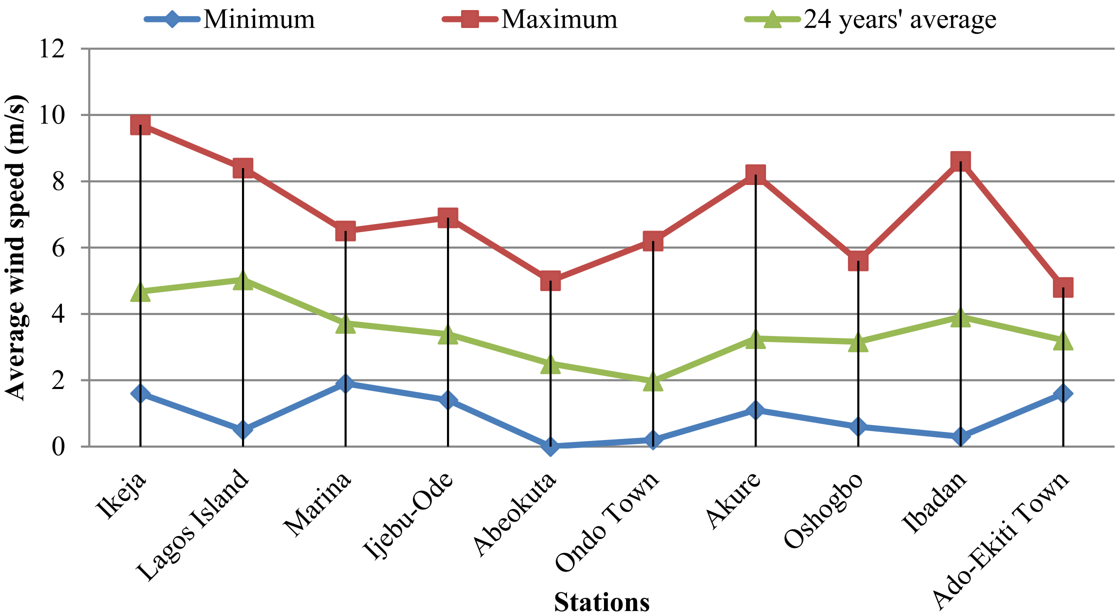


Figure 3. Range of wind speed and the stations’ 24 years’ average values.



3. Data Analysis

Various statistical probability density functions have been used to describe wind speed frequency distributions and also classify the wind profile characteristics of a site. The methods vary from the use of standard parametric distributions to distributions that relate to the principle of maximum entropy. Other methods of approach include univariate and bivariate distributions, unimodal, bimodal, bitangential (bitangentiality is implied by bimodality and occurs if there are two distinct points, v_1, v_2 at which there is a common tangent to the density curve [28]) and hybrid distributions [29–39]. Recently, the two parameters gamma distribution function, normal and lognormal, Rayleigh, Weibull and other statistical distributions have been employed [17,32,35,39]. However, of all the statistical probability density functions, the 2-parameter Weibull distribution has enjoyed wide use [15,22,39–46]. This was because some of the other distributions did not produce a good fit to the observed data. More so, where others present a better fit (e.g., the nonparametric kernel density function [47], they could not be used to determine the two important wind speeds for wind farm evaluation or carry out further technical analyses. The statistical significance of the Weibull results has also been the best [40,41,48–50].

More recently, other methods have surfaced. These include the application of Artificial Neural Networks (ANNs), Adaptive neuro-fuzzy, Mixture probability distribution functions, Autoregressive Integrated Moving Average (ARIMA) the Bayesian model averaging, the ARIMA-ANN and the ARIMA-Kalman hybrid methods to model wind speed distributions [47,51–57]. Despite the significance of these methods in predicting wind speeds profiles of a place, they also fall short in their inability to determine the two very important site specific wind speeds. These are the most probable and maximum energy carrying wind speeds. Also, the two parameters of the Weibull statistics can be employed directly to simulate the application of wind turbine at a site, a property superior to other methods. It could also be used to determine the turbine’s performance. Thus, the 2-parameter Weibull distribution has proven to be very versatile for wind profile characterisation of a place [58]. It is still regarded as the best in terms of quality and variety of application. Therefore, this study employed the method.

3.1. The Weibull Statistics

The Weibull Probability Density Function (PDF) is expressed as:

$$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

where $f(v)$ is the probability of observing wind speed v, k is the dimensionless Weibull shape parameter and c (m/s) is the Weibull scale parameter. The Cumulative Density Function (CDF) corresponding to the Weibull distribution is given as:

$$F(v)=1-\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

where $F(v)$ is the cumulative distribution function of observing wind speed v. Equation (2) can be expressed in a linear form as $y=mx+C$ as:

$$\ln\left[-\ln\left[1-F(v)\right]\right]=k\ln v-k\ln c \tag{3}$$

where $y=\ln\left[-\ln\left[1-F(v)\right]\right]$, $mx=k\ln v$ and $C=-k\ln c$

A graph of $\ln\left[-\ln\left[1-F(v)\right]\right]$ on the vertical against $\ln v$ on the abscissa leads to estimating the shape (k) and scale (c) parameters of the Weibull distribution.

3.2. Weibull Mean Wind Speed and Standard Deviation

The mean value of the wind speed v_{m} and standard deviation σ for the Weibull distribution can be estimated from [59,60]:

$$v_{\mathrm{m}}=c\Gamma\left(1+\frac{1}{k}\right) \tag{4}$$

and:

$$\sigma=\sqrt{c^{2}\left\{\Gamma\left(1+\frac{2}{k}\right)-\left[\Gamma\left(1+\frac{1}{k}\right)\right]^{2}\right\}} \tag{5}$$

where Γ( ) is the gamma function of ( ).

3.3. Most Probable and Maximum Energy Carrying Wind Speeds

The most probable (v_{mp}) and maximum energy carrying (v_{Emax}) wind speeds are expressed as:

$$v_{\mathrm{Emax}}=c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{6}$$

$$v_{\mathrm{mp}}=c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{7}$$

3.4. Weibull Wind Power Density

The Weibull wind power density per unit area can be obtained from:

$$p(v) = \frac{P(v)}{A} = \frac{1}{2}\rho c^3\left(1+\frac{3}{k}\right) \tag{8}$$

where $P(v)$ is the wind power (W), $p(v)$ is the wind power density (W/m^2) and ρ is the air density at the site.

3.5. The Goodness of Fit Test

The suitability of the Weibull distribution and the degree of convergence of its results to the sites' measured values was determined using the Kolmogorov–Smirnov (K–S) goodness of fit test [27]. The expression for the K–S test is given as:

$$d = d(v_1,\ldots,v_n) = \sqrt{n}\sup_{-\infty<x<\infty}\left|F^*(v) - F(v)\right| \tag{9}$$

where n is the sample size, $\sup\limits_{-\infty<x<\infty}$ is the supremum (or least upper bound) of the set $\left|F^*(v) - F(v)\right|$.

The P-value of K–S goodness of fit test can be estimated from the value of d using the relationship given by:

$$\left.\begin{array}{cl} P = 1 & \text{for } d < 0.22 \\ P = 1 - \dfrac{\sqrt{2\pi}}{d}\exp\left(\dfrac{-\pi^2}{8d^2}\right) & \text{for } 0.22 \le d \le 0.80 \\ P = 2\exp\left(-2d^2\right) + \exp\left(-8d^2\right) - \exp\left(-18d^2\right) & \text{for } 0.80 < d \le 3.15 \\ P = 0 & \text{for } d > 3.15 \end{array}\right\} \tag{10}$$

Therefore, at a significant level $\alpha = 0.05$, the P-Value can be compared directly with α to test the hypotheses as:

$$\begin{array}{c} H_0 : P \ge \alpha \\ H_\text{A} : P < \alpha \end{array} \tag{11}$$

where H_0 is the null hypothesis, while H_A is the alternative hypothesis.

3.6. Determination of the Degree of Accuracy of the Weibull Distribution Model Results

To estimate the degree of accuracy of the Weibull results, various estimation statistics were employed. These are the coefficient of determination, R^2, the Root Mean Square Error (RMSE) and the Nash-Sutcliffe model Coefficient of Efficiency (COE) [27,61]. They are mathematically expressed as:

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{\frac{1}{2}} \tag{12}$$

$$\text{COE} = 1 - \frac{\sum_{i=1}^{N}\left(y_i - x_i\right)^2}{\sum_{i=1}^{N}\left(y_i - \bar{x}\right)^2} \tag{13}$$

where y_i is the ith actual data, x_i is the ith Weibull result, z is the mean of the actual data and N is the number of observations. The closer the values of R^2 and COE are to one, the more accurate the result, while the closer to zero the vales of RMSE the better results.

3.7. Simulating Electrical Power Output from a Turbine Model

To simulate the electrical power output of a wind turbine model and also determine its performance, Equations (14)–(16) [21] were employed:

$$P_{\text{e}} = \begin{cases} 0 & \left(v < v_{\text{c}}\right) \\ P_{\text{eR}}\dfrac{v^{\text{k}} - v_{\text{c}}^{\text{k}}}{v_{\text{R}}^{\text{k}} - v_{\text{c}}^{\text{k}}} & v_{\text{c}} \le v \le v_{\text{R}} \\ P_{\text{eR}} & v_{\text{R}} \le v \le v_{\text{F}} \\ 0 & v > v_{\text{F}} \end{cases} \tag{14}$$

The average power output ($P_{\text{e,ave}}$) of a turbine model is given as:

$$P_{e,ave} = P_{eR}\left\{\frac{e^{-\left(v_c/c\right)^k} - e^{-\left(v_R/c\right)^k}}{\left(v_R/c\right)^k - \left(v_c/c\right)^k} - e^{\left(v_F/c\right)^k}\right\} \tag{15}$$

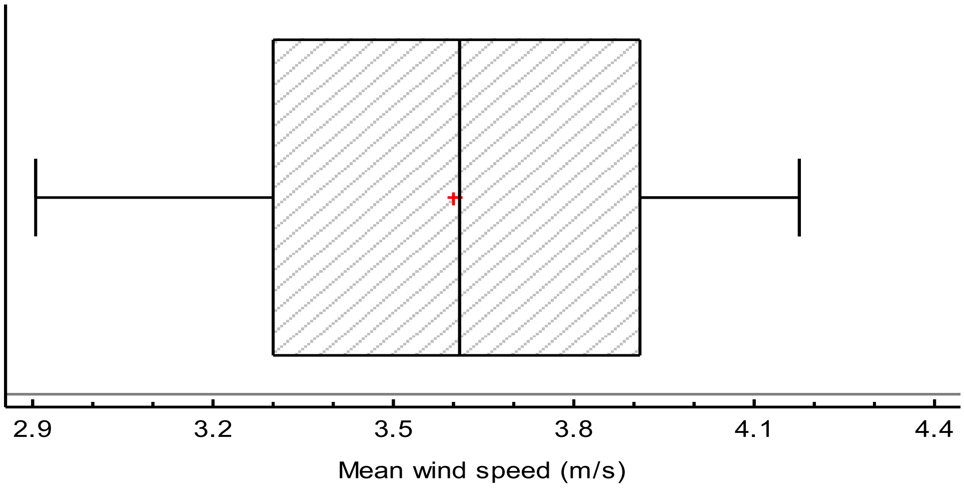
where: v_{c} = cut in wind speed, v_{R} = rated wind speed, v_{F} = cut off wind speed and P_{eR} = rated electrical power. The capacity factor, CF, is given as:

$$\text{CF} = \frac{P_{\text{e,ave}}}{P_{\text{eR}}} \tag{16}$$

4. Results and Discussion

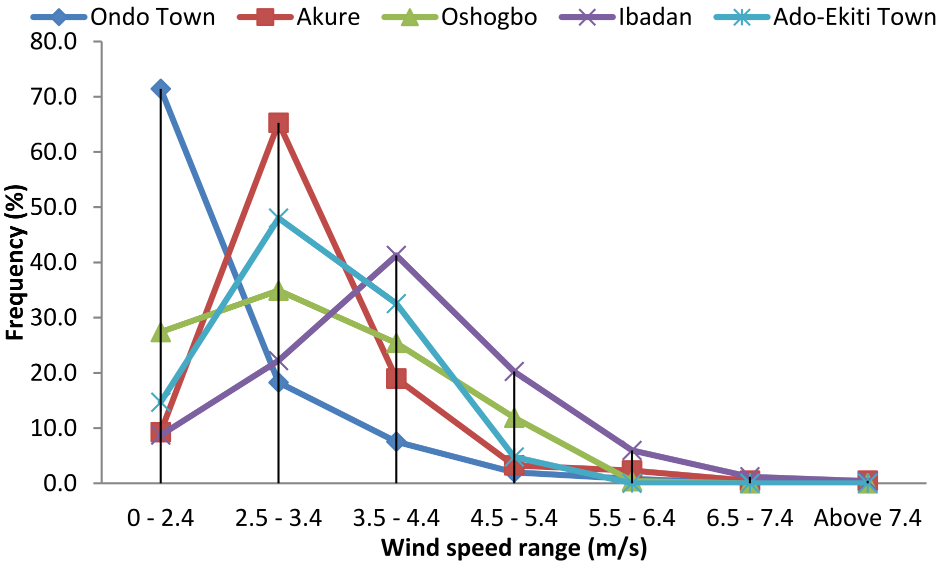
Analysis of the value distribution of the measured wind speeds of the stations gave Figure 4. The statistical data tolerance limit for the whole population at 95% confidence level and 99% certainty also gave 3.602 ± 1.661 m/s The standard skewness and standard kurtosis of the data distribution was estimated to be −0.309 and −0.631, respectively. These values show that the wind speed data at the sites falls into the range for normal distribution. Based on this, at 95% statistical confidence, it can be stated that 99% of the wind speed data from the ten stations were between 1.9 and 5.3 m/s.

Figure 4. Box and whiskers plot showing range of mean wind speed across the stations.



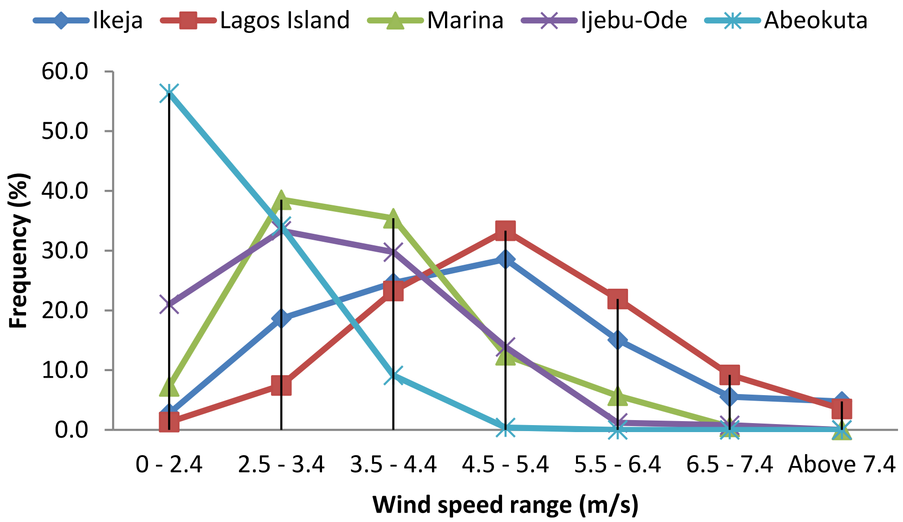
Moreover, Figure 2 reveals fluctuations in the distributions of the mean measured wind speeds as is common with real life and climatic data because of their dynamic nature. September to November were the months with the least wind supply across all the stations. Site by site analysis of the measured wind speed data across the 24 years period reveals that Lagos Island experienced the best wind speed profile. Analysis of the measured wind speeds' frequency of occurrence for the stations is presented in Figure 5. Figure 5 therefore demonstrates that stations within Lagos State (Ikeja, Lagos Island and Marina) experience better wind speed bands than the others. Mean wind speeds majorly within the range 2.5 to 6.4 m/s characterized stations in Lagos, while the other stations experiences mean wind speeds below 4.5 m/s.

Figure 5. Wind speed Frequency of occurrence for (**a**) stations in Ondo, Osun, Oyo and Ekiti States; (**b**) stations in Lagos and Ogun States.



(**a**)

Figure 5. *Cont.*



(b)

The results of the Weibull statistical analysis are presented in Table 2 and the plots of the CDF and PDF for the whole data and seasons (Figures 6–11) demonstrate that the stations' wind profiles follow the same cumulative and probability distribution patterns. Figures 6 and 7 demonstrate that up to 50% of the whole data series were values that ranged from about 1.9 to 5.0 m/s, while up to 80% of the data series were values that ranged from about 2.8 to 6.1 m/s. Mean wind speed values across the stations also ranged from about 2.0 to 5.0 m/s. The dry season Weibull plots of Figure 8 indicate that up to 50% of the dry season's data across the stations were values that ranged from about 1.4 to 4.6 m/s, while up to 80% of the data were values that ranged from 2.3 to 5.7 m/s.

Table 2. The range of some important Weibull results for the stations.

Range of Values relating to important Weibull results at 10 m height									
Station	V_{actual}	σ_{actual}	$V_{weibull}$ **(m/s)**	$\sigma_{weibull}$	k	c **(m/s)**	V_{mp} **(m/s)**	V_{Emax} **(m/s)**	**Estimated Power (W/m²)**
Lagos Island	4.1–5.8	0.9–1.6	4.1–5.7	0.9–2.9	1.8–5.8	4.4–6.2	3.4–6.2	4.7–8.6	83.8–320.3
Ikeja	3.5–5.8	1.0–1.6	3.5–5.8	3.9–6.3	3.6–4.8	3.9–6.3	3.6–5.9	4.3–6.9	64.0–264.6
Ibadan	2.9–4.7	0.6–1.5	2.9–4.7	0.6–2.2	1.7–6.9	3.2–5.3	2.4–4.8	3.6–6.6	36.7–164.7
Marina	3.2–4.8	0.4–1.2	3.2–4.8	0.5–1.4	3.7–8.1	3.5–5.3	3.3–4.9	3.6 – 6.0	36.2–165.1
Ijebu Ode	2.4–4.2	0.6–1.2	2.4–4.2	0.6–1.1	3.5–6.2	2.6–4.6	2.5–4.4	2.9–4.9	18.5–94.4
Oshogbo	2.0–4.0	0.5–1.0	2.0–4.0	0.5–1.0	2.7–5.5	2.2–4.4	1.9–4.2	2.7–4.8	16.1–85.6
Ekiti	2.3–4.1	0.3–0.7	2.3–4.1	0.3–0.7	5.4–12.2	2.5–4.3	2.4–4.3	2.6–4.4	13.3–65.9
Akure	2.7–4.0	0.2–1.4	2.7–4.0	0.3–1.2	2.9–14.2	2.9–4.4	2.9–4.1	3.1–4.8	21.1–88.5
Abeokuta	2.4–2.7	0.5–1.0	2.4–2.8	0.5–0.9	3.2–5.6	2.6–3.1	2.5–2.8	2.8–3.5	16.3–24.9
Ondo	1.2–2.8	0.7–1.2	1.1–2.9	0.7–1.1	1.3–3.5	1.3–3.2	0.4–2.9	2.2–3.7	3.6–37.2

Figure 6. Whole year's CDF Plots of all the stations.

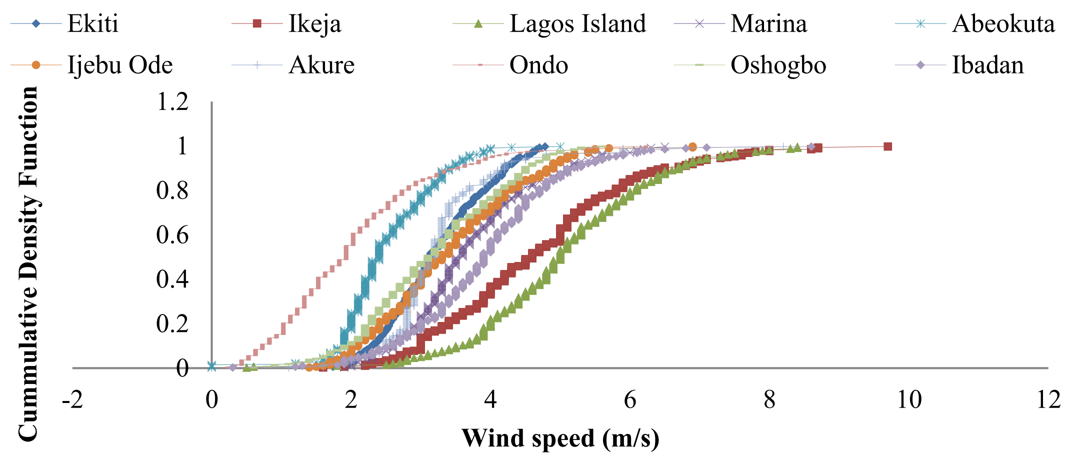


Figure 7. Whole year's PDF Plots of all the stations.

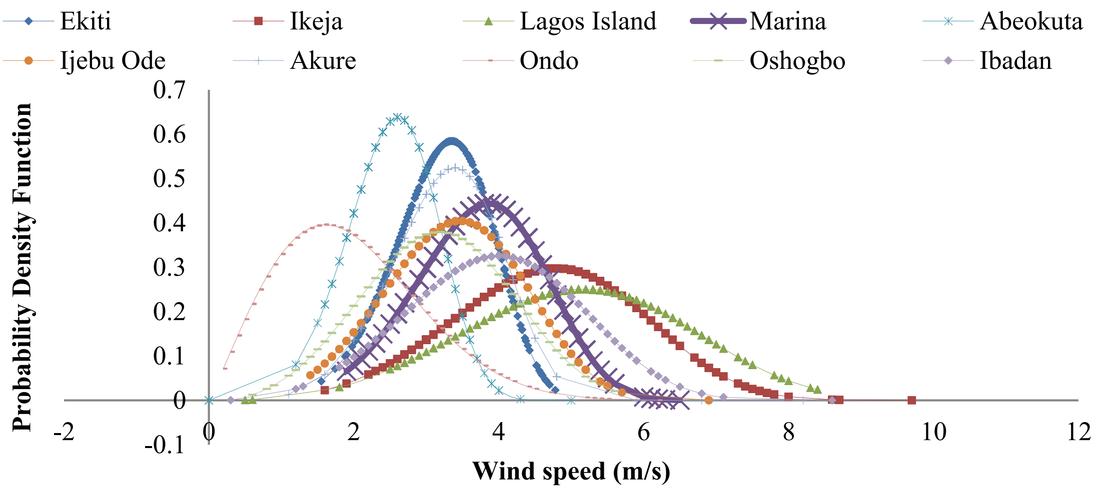


Figure 8. Dry Season's CDF Plots of all the stations.

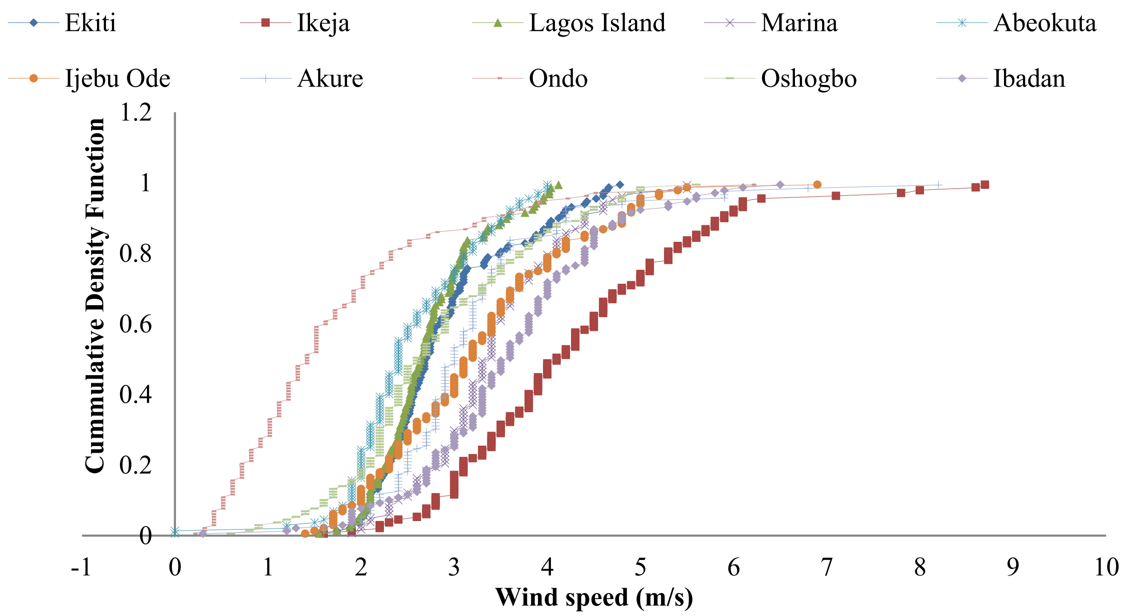


Figure 9. Dry Season's PDF Plots of all the stations.

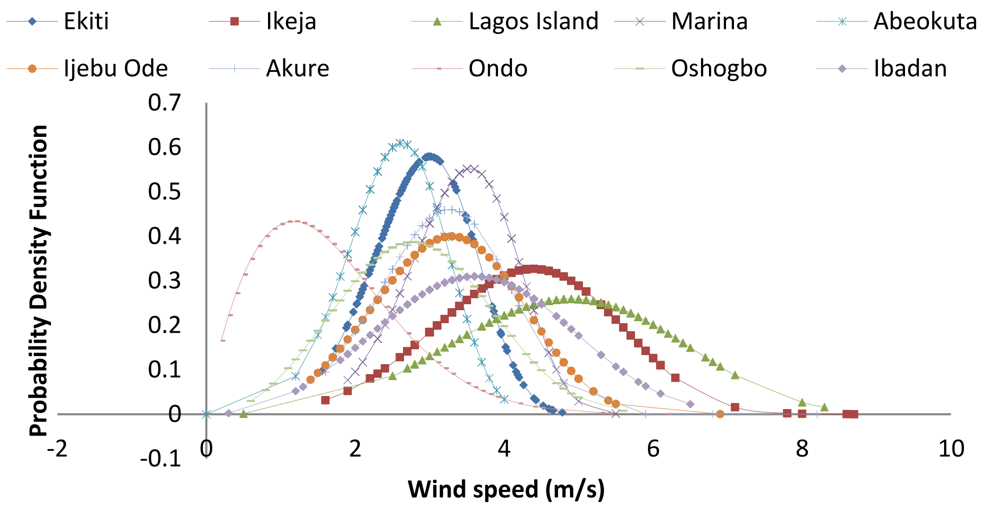


Figure 10. Wet Season's CDF Plots of all the stations.

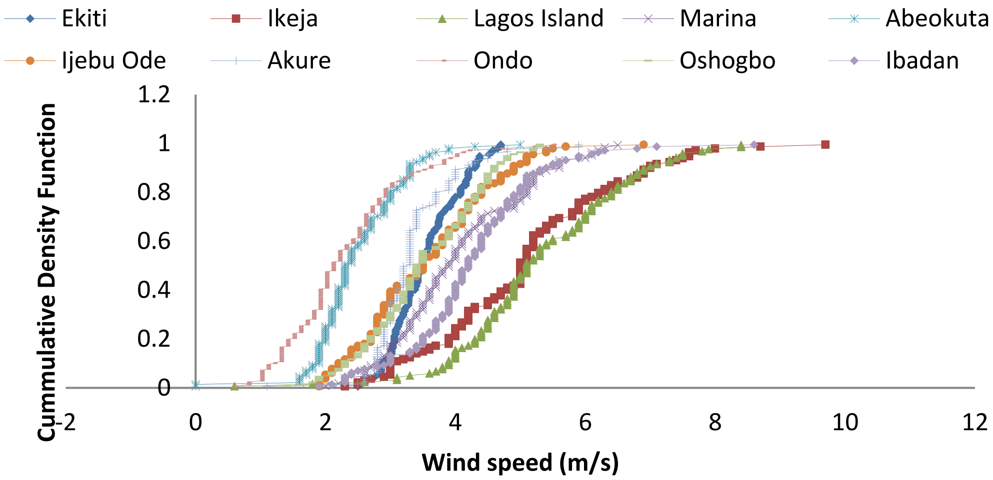
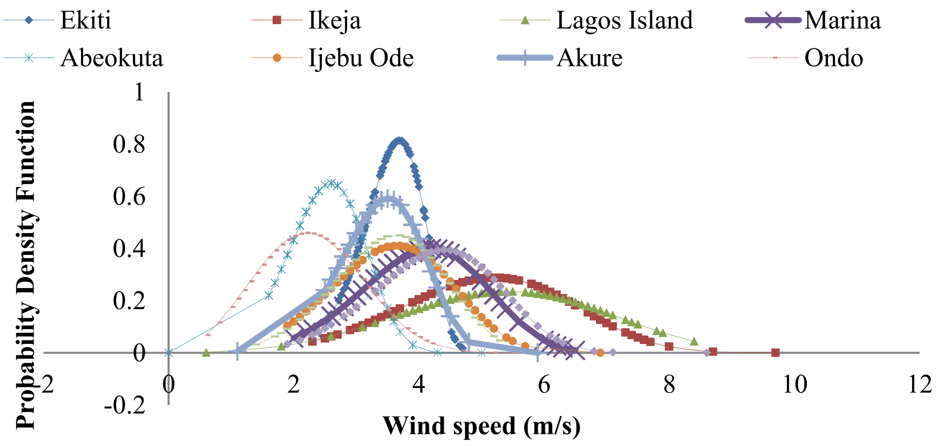


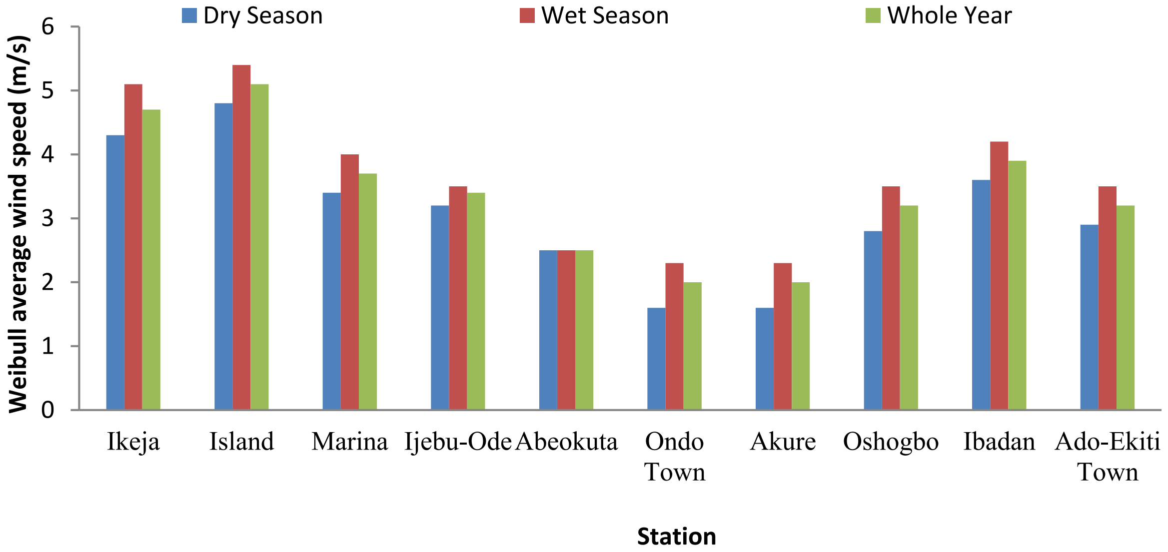
Figure 11. Wet Season's PDF Plots of all the stations.



Based on the Weibull results, the ranking of the stations from the best to the least follow in order from Lagos Island (4.1–5.7 m/s), Ikeja (3.5–5.8 m/s) and Ibadan (2.9–4.7 m/s) as the top three stations. Marina (3.2–4.8 m/s), Ijebu Ode (2.4–4.2 m/s), Ado Ekiti (2.3–4.1 m/s), Oshogbo (2.0–4.0 m/s) and Abeokuta (2.4–2.8 m/s) are the next five stations in rank. Ondo and Akure are the least, with Weibull wind speed results ranged from 1.1 to 2.9 m/s respectively. The period of highest potential for wind energy harvest falls within February to July and that for lowest yield was within September to November across the stations.

Seasonally (Figures 10 and 12), the wet season (April to September) produced the better average wind speed profiles than the dry (October to March). Figure 10 moreover, demonstrates that up to 50% of the wet season data series were values that ranged from about 2.1 to 5.2 m/s and up to 80% of the data ranged from 2.3 to 5.7 m/s. Figures 8 and 10 are the PDF plots of the dry and wet season's data series.

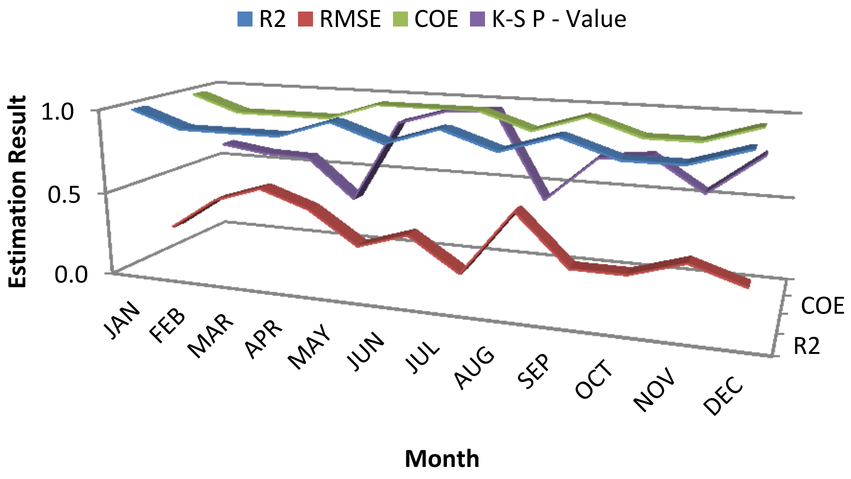
Figure 12. Weibull results showing the average wind speed values for the seasons (dry and wet) and whole years' analysis.



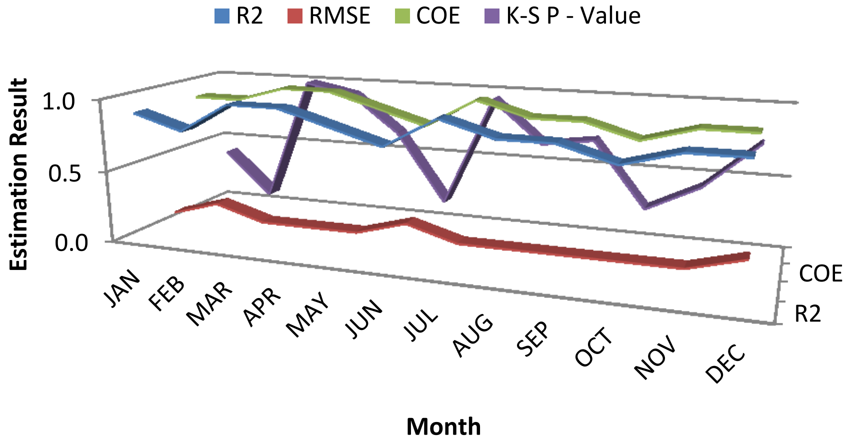
The appropriateness of the Weibull distribution, in terms of its accuracy and goodness-of-fit to the sites wind speed data were determined and the results show adequacy. Figure 13 presents the performance estimation results of R^2, RMSE, COE and K–S statistics. The values of K–S statistics for all the stations' data were greater than 0.05 and the range of values for R^2 and COE were mostly between 0.9 and 1.0.

The values of k and c from the analysis across all the stations ranged between $1.3 \leq k \leq 12.2$ and $1.3 \leq c \leq 6.3$ m/s respectively. These high values of k and c ($k \geq 2$ and $c \geq 2$ m/s) indicate a data spread in the normal distribution [59], and also shows that the data spread exhibits good uniformity with relatively small scatter. According to Keyhani *et al*. [60], the scale parameter c, indicates how windy a location under consideration is, while the shape parameter k, indicate how peaked the wind distribution is. Thus, if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and will be very peaked. Also shown in Table 2 are the most probable (or modal) wind speed v_{mp}, and the wind speed carrying maximum wind energy v_{Emax}, Weibull standard deviations (σ), and Weibull power density.

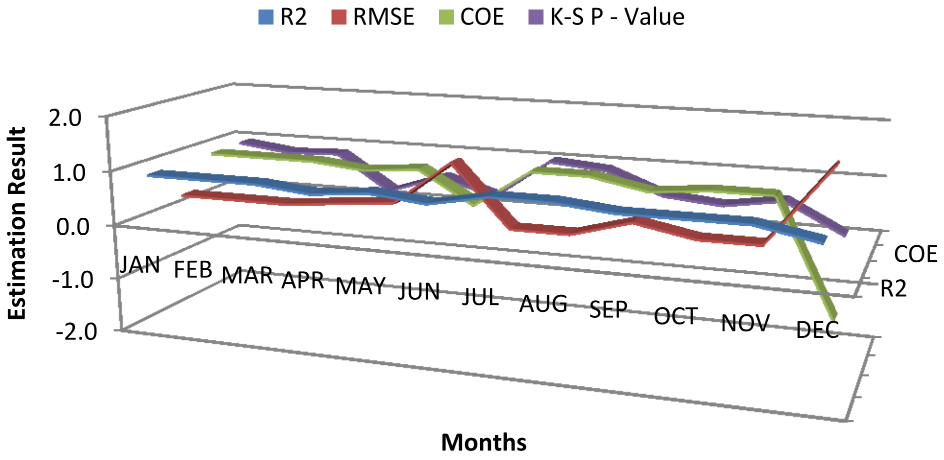
Figure 13. Estimation of the accuracy and goodness-of-fit of the Weibull distribution to the sites wind speed data: (**a**) Ado Ekiti; (**b**) Ikeja; (**c**) Lagos Island; (**d**) Marina; (**e**) Abeokuta; (**f**) Ijebu Ode; (**g**) Akure; (**h**) Ondo; (**i**) Oshogbo; and (**j**) Ibadan.



(**a**)

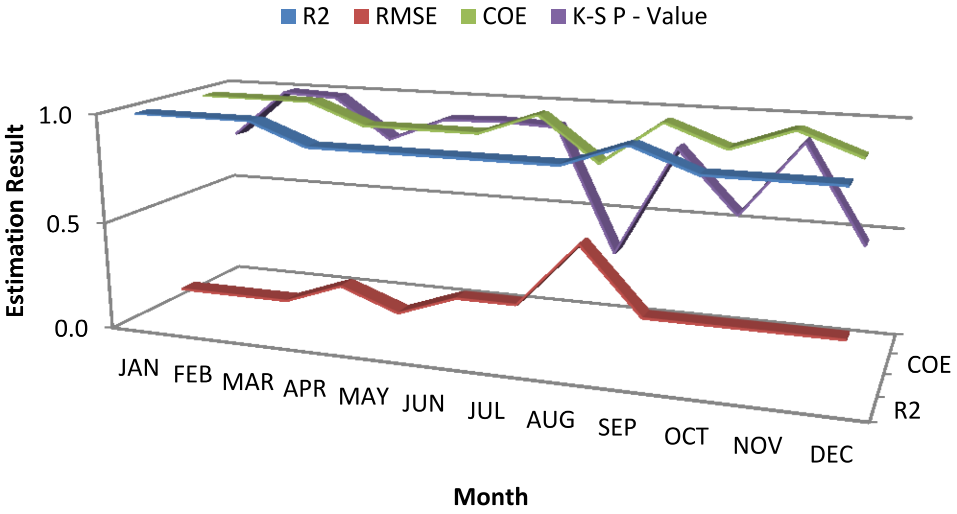


(**b**)

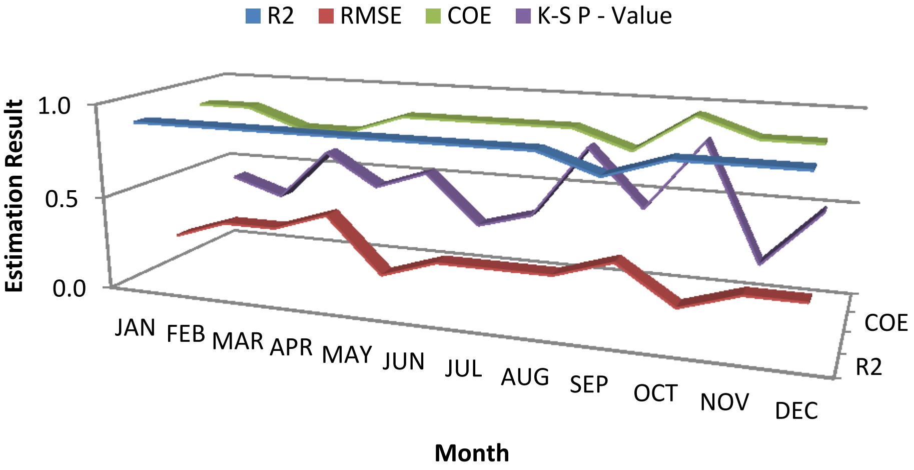


(**c**)

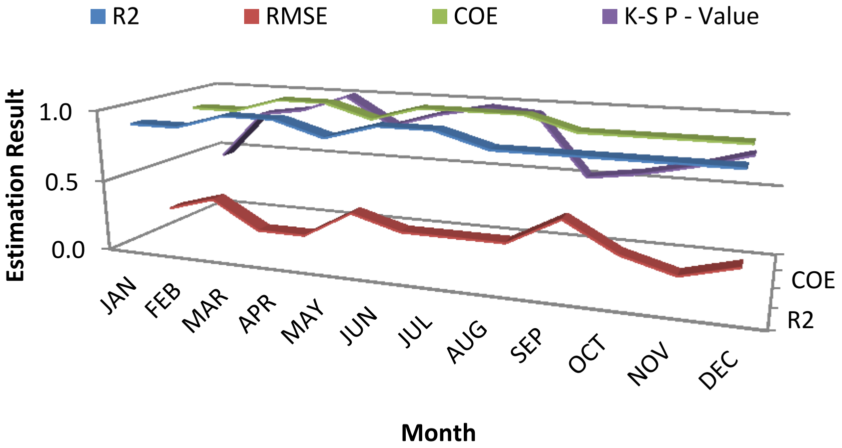
Figure 13. *Cont.*



(d)

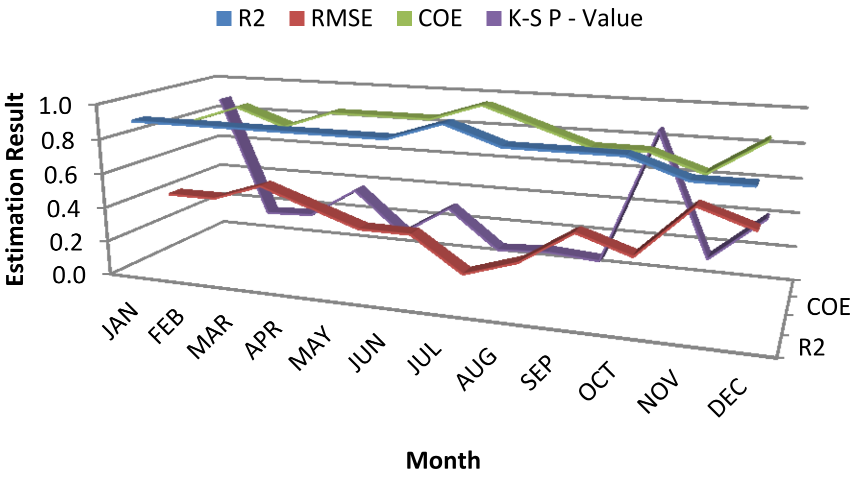


(e)

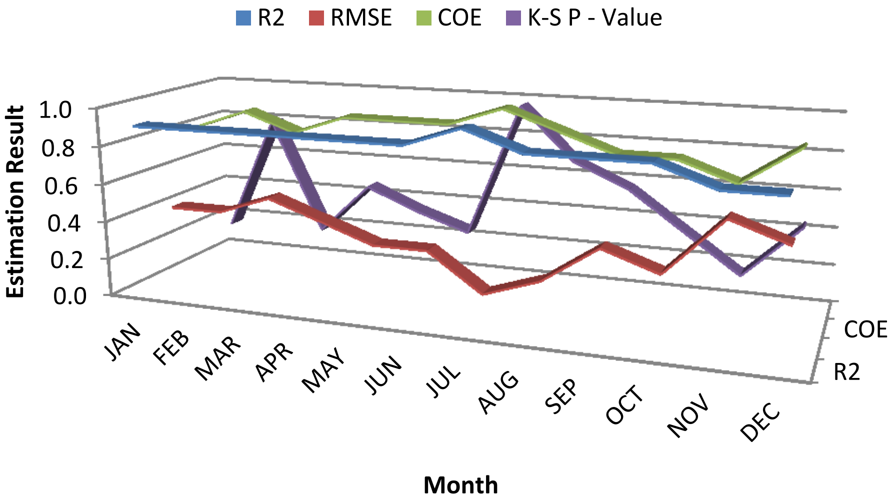


(f)

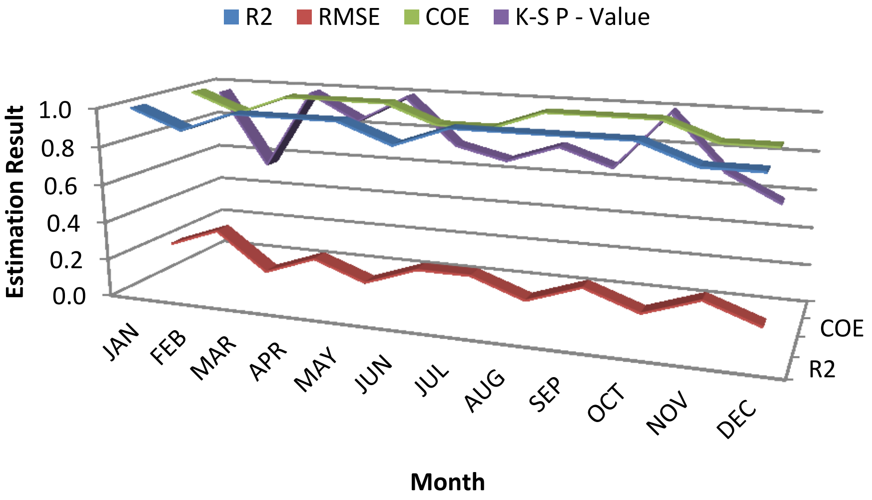
Figure 13. *Cont.*



(**g**)

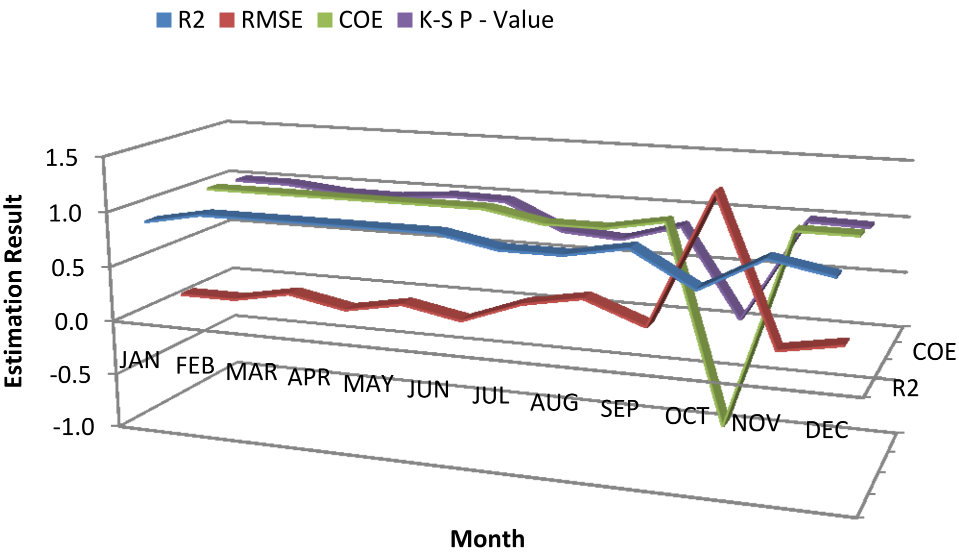


(**h**)



(**i**)

Figure 13. *Cont.*



(j)

4.1. Adapting Practical Wind Turbine Models to the Sites

Five practical wind turbine models were employed. The technical parameters of the turbines are presented in Table 3. These turbines were matched to the sites' wind profiles at the turbines' hub heights. The results gave the likely wind power that may be generated if the turbine machines were installed at the sites. However, based on the fact that the turbines hub heights were above 10 m, the wind profile characteristics were estimated for this height using Equation (17) [24]. This was because NIMET's data are only at 10 m height. NIMET does not take or store data apart from those at this height:

$$v_{\mathrm{ref}} = v_{10} \times \left(\frac{h_{\mathrm{ref}}}{h_{10}}\right)^{\alpha} \tag{17}$$

where v_{ref} = wind speed at reference height, v_{10} = wind speed at 10 m height, $\mathrm{h}_{\mathrm{ref}}$ = reference height, h_{10} = 10 m height, α = roughness factor for the sites. The commonest and widely accepted value of α for most sites is 0.143. The results are presented in Table 4.

Table 3. Technical parameters of wind turbine models used in the analysis [41,62].

Wind Machine	V_c (m/s)	V_F (m/s)	V_R (m/s)	P_{eR} (kW)	Hub Height (m)	Rotor Diameter (m)	Assumed Price (€)
Bonus 2300/82.4	3	25	15	2,300	60	82.4	2,300,000
Bonus 2000/76	4	25	15	2,000	60	76	2,000,000
Bonus 300/33.4	3	25	13	300	30	33.4	300,000
GE 1.5sle	3.5	25	14	1,500	65/80	77	1,500,000
GE 1.5xle	3.5	20	11.5	1,500	80	82.5	1,500,000

Table 4. Results of simulating electrical power output of a model wind turbine.

Model	**Bonus 2300/82.4**			**Bonus 2000/76**			**Bonus 300/33.4**		
Station	P_{e} (kW)	P_{eAve} (kW)	CF (%)	P_{e} (kW)	P_{eAve} (kW)	CF (%)	P_{e} (kW)	P_{eAve} (kW)	CF (%)
Lagos Island	60.12	239.18	10.40	47.97	204.09	10.20	11.64	28.53	9.51
Ikeja	28.56	136.86	5.95	22.15	116.50	5.83	5.87	16.04	5.35
Marina	3.33	26.83	1.17	2.00	22.47	1.12	0.78	2.97	0.99
Ibadan	17.75	93.10	4.05	11.17	77.03	3.85	3.51	10.56	3.52
Ijebu Ode	5.76	40.95	1.78	2.07	32.90	1.65	1.15	4.43	1.48
Akure	1.13	12.01	0.52	0.29	9.79	0.49	0.26	1.27	0.42
Oshogbo	7.91	54.30	2.36	0.79	41.92	2.10	1.35	5.72	1.91
Ekiti	0.51	6.56	0.29	0.10	5.38	0.27	0.13	0.69	0.23
Ondo	0.00	66.21	2.88	0.00	37.41	1.87	0.00	5.24	1.75
Abeokuta	0.18	5.04	0.22	0.00	3.47	0.17	0.00	0.45	0.15
Model	**GE 1.5sle**			**GE 1.5xle**			-	-	-
Station	P_{e} (kW)	P_{eAve} (kW)	CF (%)	P_{e} (kW)	P_{eAve} (kW)	CF (%)	-	-	-
Lagos Island	56.71	297.26	19.82	138.08	633.97	42.26	-	-	-
Ikeja	27.42	182.70	12.18	72.34	460.10	30.67	-	-	-
Marina	3.19	41.68	2.78	10.07	131.73	8.78	-	-	-
Ibadan	15.48	118.49	7.90	37.89	288.15	19.21	-	-	-
Ijebu Ode	4.66	55.05	3.67	12.14	143.28	9.55	-	-	-
Akure	0.98	19.44	1.30	3.24	64.09	4.27	-	-	-
Oshogbo	5.47	66.66	4.44	12.63	153.92	10.26	-	-	-
Ekiti	0.46	11.61	0.77	1.69	42.90	2.86	-	-	-
Ondo	0.00	63.42	4.23	0.00	106.38	7.09	-	-	-
Abeokuta	0.00	7.81	0.52	0.00	23.93	1.60	-	-	-

Table 4 clearly shows that if the turbine models were employed at the sites, the magnitude of average power generation per annum for each turbine will vary as ($5.04 \leq P_{\mathrm{eAve}} \leq 239.18$) kW, ($3.47 \leq P_{\mathrm{eAve}} \leq 204.09$) kW and ($0.45 \leq P_{\mathrm{eAve}} \leq 28.53$) kW for Bonus 2300/82.4, Bonus 2000/76 and Bonus 300/33.4 respectively. For GE 1.5sle and GE 1.5xle, the magnitude of production will vary as ($7.81 \leq P_{\mathrm{eAve}} \leq 297.26$) kW and ($23.93 \leq P_{\mathrm{eAve}} \leq 633.97$) kW, respectively. Clearly, Table 4 shows that Turbine machine model GE 1.5xle gave the best production of all the models. This is closely followed in order by GE 1.5sle, Bonus 2300/82.4, Bonus 2000/76 and Bonus 300/33.4, respectively. Based on this, it can be concluded that the best turbine matching parameter that will produce excellently at the sites will be machines whose wind speed (m/s) rating is: (v_{c} = between 2.0 and 3.0 m/s; v_{R} = between 10.0 and 12.0 m/s).

Furthermore, going by the values of the capacity factor, the turbines will underperform at some of the sites. This is because the rated wind speeds of the turbines are far above the wind speed bands of the sites. Only Stations in Lagos State and Ibadan are closer with reasonable values of v_{Emax} (Table 2). This is suggestive of the fact that smaller wind turbine machine ratings, coupled with speed ratings stated earlier, would be better suited to such sites. Hence, those sites can be appropriate for small scale wind power generation instead of as mega stations. However, although as demonstrated by the turbine matching results, some of the sites may not be applicable for large scale megawatt turbine utilisation, they may invariably be appropriate for small turbines connected together as wind farms to generate large scale power, up to the megawatt and giga-watt statuses. Thus, each of the sites can be employed for wind farm development housing many small wind turbines connected together for power generation. Further to this, the values of the CF suggest that employing the turbines for wind power generation may be economically infeasible for most of the sites. Hence employing smaller wind turbines with low wind speed ratings will be very appropriate for the sites.

4.2. Cost Benefit Analysis

The cost benefit of generating wind electricity at the sites with the aid of the turbine models were carried out using Equations (18) and (19). The assumed economic parameters and the turbine prices are shown in Tables 3 and 5.

The bases for the assumptions are discussed in Ajayi *et al.* [61]:

$$C_{\mathrm{SC/kWh}} = \frac{C_{\mathrm{PV}}}{\text{Annual } P_{\mathrm{e,ave}} \times t} \tag{18}$$

$$C_{\mathrm{PV}} = x\left(1+R_{\mathrm{C}}\right) + \frac{x}{t} R_{\mathrm{om}} \left[\frac{1+I_{\mathrm{R}}}{R_{\mathrm{I}} - I_{\mathrm{R}}}\right] \times \left[1 - \left(\frac{1+I_{\mathrm{R}}}{1+R_{\mathrm{I}}}\right)^{t}\right] - xR_{\mathrm{sc}}\left(1+R_{\mathrm{C}}\right)\left(\frac{1+I_{\mathrm{R}}}{1+R_{\mathrm{I}}}\right)^{t} \tag{19}$$

where C_{pv} = present value cost, x = turbine price, R_{C} = rate chargeable on turbine price to arrive at the cost for civil/structural works, R_{om} = rate chargeable on annual turbine price to arrive at the cost for Operation and Maintenance, R_{I} = prevailing interest rate, I_{R} = prevailing inflation rate, R_{SC} = rate chargeable on total investment cost, t = turbine life or period of operation of turbine, $C_{\mathrm{SC/kWh}}$ = specific cost per kWh of wind electricity.

Table 5. Assumptions used for the econometrics analysis [24,61,63].

Item	**Assumed value**
R_{C}	20.0%
R_{OM}	25.0%
R_{I}	12.0%
I_{R}	8.6%
R_{SC}	10.0%
t	20.0 years

Table 6 presents the cost of producing wind electricity per kWh with the turbine models. It shows that using GE 1.5xle at the sites will result in a production cost ranging between 0.02 € and 0.47 € per kWh while employing Bonus 300/33.4 will require between 0.08 € and 5.03 € per kWh.

Table 6. Economic cost benefit of generating wind electricity using different turbine models.

Location	**C_{pv} (€)**	**Average P_{eAve} per annum × 106 kWh**	**20 years average P_{eAve} ($t \times P_{eAve}$) × 106 kWh**	**Specific cost per kWh (€)**
Station			**Bonus 2300/82.4**	
Lagos Island	3,033,617.2	2.1	41.9	0.07
Ikeja	3,033,617.2	1.2	24	0.13
Marina	3,033,617.2	0.235	4.7	0.65
Ibadan	3,033,617.2	0.816	16.3	0.19
Ijebu Ode	3,033,617.2	0.359	7.17	0.42
Akure	3,033,617.2	0.105	2.1	1.44
Oshogbo	3,033,617.2	0.476	9.51	0.32
Ekiti	3,033,617.2	0.058	1.15	2.64
Ondo	3,033,617.2	0.58	11.6	0.26
Abeokuta	3,033,617.2	0.044	0.88	3.44
Station			**Bonus 2000/76**	
Lagos Island	2,637,928	1.79	35.8	0.07
Ikeja	2,637,928	1.02	20.4	0.13
Marina	2,637,928	0.2	3.94	0.67
Ibadan	2,637,928	0.68	13.5	0.20
Ijebu Ode	2,637,928	0.29	5.76	0.46
Akure	2,637,928	0.086	1.72	1.54
Oshogbo	2,637,928	0.37	7.34	0.36
Ekiti	2,637,928	0.047	0.94	2.80
Ondo	2,637,928	0.33	6.55	0.40
Abeokuta	2,637,928	0.03	0.61	4.33
Station			**Bonus 300/33.4**	
Lagos Island	395,689.2	0.25	5	0.08
Ikeja	395,689.2	0.14	2.81	0.14
Marina	395,689.2	0.03	0.52	0.76
Ibadan	395,689.2	0.09	1.85	0.21
Ijebu Ode	395,689.2	0.04	0.78	0.51
Akure	395,689.2	0.01	0.22	1.78
Oshogbo	395,689.2	0.05	1	0.39
Ekiti	395,689.2	0.006	0.12	3.29
Ondo	395,689.2	0.05	0.92	0.43
Abeokuta	395,689.2	0.004	0.08	5.03
Station			**GE 1.5sle**	
Lagos Island	1,961,325	2.6	52.1	0.04
Ikeja	1,961,325	1.6	32	0.06
Marina	1,961,325	0.37	7.3	0.27
Ibadan	1,961,325	1.04	20.8	0.09
Ijebu Ode	1,961,325	0.48	9.64	0.20
Akure	1,961,325	0.17	3.41	0.58
Oshogbo	1,961,325	0.58	11.17	0.17
Ekiti	1,961,325	0.1	2.03	0.96
Ondo	1,961,325	0.56	11.1	0.18
Abeokuta	1,961,325	0.07	1.37	1.43

Table 6. *Cont.*

Location	C_{pv} (€)	Average P_{eAve} per annum × 106 kWh	20 years average P_{eAve} (t × P_{eAve}) × 106 kWh	Specific cost per kWh (€)
station		**GE 1.5xle**		
Lagos Island	1961325	5.55	118	0.02
Ikeja	1961325	4.03	80.6	0.02
Marina	1961325	1.15	23.1	0.08
Ibadan	1961325	2.52	50.5	0.04
Ijebu Ode	1961325	1.26	25.1	0.08
Akure	1961325	0.56	11.2	0.17
Oshogbo	1961325	1.35	27	0.07
Ekiti	1961325	0.38	7.52	0.26
Ondo	1961325	0.93	18.6	0.11
Abeokuta	1961325	0.21	4.19	0.47

5. Conclusions

This study focused on assessing the wind power potential and energy cost analysis of wind power generation at ten South West Nigerian sites/stations. The purpose of the study was to expose the region's wind profile characteristics for power generation. The outcome proved that the region's wind profiles and characteristics are suitable for wind power generation. Average wind speeds of between 1.9 and 5.3 m/s are prevalent, while the most probable wind speed ranged between 1.9 and 6.2 m/s. The maximum energy carrying wind speeds ranged between 2.2 and 8.6 m/s across all the stations. Lagos and Oyo states are areas with very high potential for harvesting wind power, while the mountainous regions of Ogun, Ondo and Ekiti would also be very suitable. Further to this, the results proved that, apart from sites in Lagos and Oyo States and in mountainous regions, lower wind speed rated turbine machines will be more appropriate for the sites. Specifically, turbines with rated cut-in wind speed of between 2.0 and 3.0 m/s will be valuable. In terms of the rated wind speed (v_R), wind turbines with rated speeds of between 10 and 12.0 m/s will be excellent for the sites.

Author Contributions

The research was designed by Oluseyi O. Ajayi. All the authors contributed to the data collection, analysis, and paper write up.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Ajayi, O.O.; Ohijeagbon, O.D.; Nwadialo, C.E.; Olasope, O. New model to estimate daily global solar radiation over Nigeria. *Sustain. Energy Technol. Assess.* **2014**, *5*, 28–36.
2. Omole, D.O.; Ndambuki, J.M. Sustainable living in Africa: Case of water, sanitation, air pollution & energy. *Sustainability* **2014**, *6*, 5187–5202.

3. Ajayi, O.O. Nigeria's energy policy: Inferences, analysis and legal ethics towards RE development. *Energy Policy* **2013**, *60*, 61–67.
4. Ajayi, O.O. Sustainable energy development and environmental protection: The case of five West African Countries. *Renew. Sustain. Energy Rev.* **2013**, *26*, 532–539.
5. Ajayi, O.O. Assessment of utilization of wind energy resources in Nigeria. *Energy Policy* **2009**, *37*, 720–723.
6. Ajayi, O.O. The potential for wind energy in Nigeria. *Wind Eng.* **2010**, *34*, 303–312.
7. Ajayi, O.O. Development of Wind Energy Models and Maps for Nigeria. Ph.D. Thesis, Covenant University, Ota, Nigeria, October 2011.
8. Adejokun, J.A. The three-dimensional Structure of the inter-tropical discontinuity over Nigeria. *Nigerian Met. Serv. Tech. Note* **1966**, *39*, 1–9.
9. Fagbenle, R.O.; Fasade, A.O.; Amuludun, A.K.; Lala, P.O. Wind energy potential of Nigeria. In Proceedings of 12th Biennial Conference of West Africa Science Association, University of Ife, Osogbo, Nigeria, 20–26 July 1980.
10. Ojosu, J.O.; Salawu, R.I. A Survey of wind energy potential in Nigeria. *Sol. Wind Technol.* **1990**, *7*, 155–167.
11. Ojosu, J.O.; Salawu, R.I. An evaluation of wind energy potential as a power generation source in Nigeria. *Sol. Wind Technol.* **1990**, *7*, 663–673.
12. Adekoya, L.O.; Adewale, A.A. Wind energy potential of Nigeria. *Renew. Energy* **1992**, *2*, 35–39.
13. Fagbenle, R.O.; Karayiannis, T.G. On the wind energy resources of Nigeria. *Int. J. Energy Res.* **1994**, *18*, 493–508.
14. Asiegbu, A.D.; Iwuoha, G.S. Studies of wind resources in Umudike, South East Nigeria—An assessment of economic viability. *J. Eng. Appl. Sci.* **2007**, *2*, 1539–1541.
15. Fadare, D.A. Statistical analysis of wind energy potential in Ibadan, Nigeria, based on weibull distribution function. *Pac. J. Sci. Technol.* **2008**, *9*, 110–119.
16. Ogbonnaya, I.O.; Chikuni, E.; Govender, P. Prospect of wind energy in Nigeria. Available online: http://active.cput.ac.za/energy/web/due/papers/2007/023O_Okoro.pdf (accessed on 16 July 2009).
17. Ngala, G.M.; Alkali, B.; Aji, M.A. Viability of wind energy as a power generation source in maiduguri, Borno state, Nigeria. *Renew. Energy* **2007**, *32*, 2242–2246.
18. ECN-UNDP (Energy Commission of Nigeria-United Nations Development of Nigeria). Renewable energy master plan: Final draft report, 2005. Available online: http://www.iceednigeria.org/REMP%20Final%20Report.pdf (accessed on 17 June 2007).
19. Lahmeyer (International) Consultants. *Report on Nigeria Wind Power Mapping Projects*; Federal Ministry Science Technology: Abuja, Nigeria, 2005; pp. 37–51.
20. Fadare, D.A. The application of artificial neural networks to mapping of wind speed profile for energy application in Nigeria. *Appl. Energy* **2010**, *87*, 934–942.
21. Fagbenle, R.O.; Katende, J.; Ajayi, O.O.; Okeniyi, J.O. Assessment of wind energy potential of two sites in North East, Nigeria. *Renew. Energy* **2011**, *36*, 1277–1283.
22. Miller, C.; Cotter, J. An Impending storm–Impacts of deforestation on weather patterns and agriculture 2013. Available online: http://www.greenpeace.org/international/Global/international/publications/forests/2013/JN455-An-Impending-Storm.pdf (accessed on 20 May 2014).

23. Eichelberger, S.; Mccaa, J.; Nijssen, B.; Wood, A. Climate change effects on wind speed. North America Wind Power®, 2008. Available online: http://c0402442.cdn.cloudfiles.rackspacecloud.com/static/ttcms/1.0.0.42/us/documents/NAWP-July08.pdf (accessed on 26 February 2014).
24. Ajayi, O.O.; Fagbenle, R.O.; Katende, J. Wind profile characteristics and econometric analysis of wind power generation of a site in Sokoto State, Nigeria. *Energy Sci. Technol.* **2011**, *1*, 54–66.
25. Ajayi, O.O.; Fagbenle, R.O.; Katende, J.; Okeniyi, J.O.; Omotosho, O.A. Wind energy potential for power generation of a local site in Gusau, Nigeria. *Int. J. Energy Clean Environ.* **2010**, *11*, 99–116.
26. Ahmed, A.; El-Suleiman, A.; Nasir, A. An assessment of wind energy resource in north central Nigeria, Plateau. *Sci. J. Energy Eng.* **2013**, *1*, 13–17.
27. Ajayi, O.O.; Fagbenle, R.O.; Katende, J.; Okeniyi, J.O. Availability of wind energy resource potential for power generation of Jos, Nigeria. *Front. Energy* **2011**, *5*, 376–385.
28. Ajayi, O.O.; Fagbenle, R.O.; Katende, J. Assessment of wind power potential and wind electricity generation using WECS of two sites in South West, Nigeria. *Int. J. Energy Sci.* **2011**, *1*, 78–92.
29. Justus, C.G. *Winds and Wind System Performance*, 1st ed.; Franklin Institute Press: Philadelphia, PA, USA, 1978.
30. Auwera, L.V.; Meyer, F.; Malet, L.M. The use of the Weibull three-parameter model for estimating mean wind power densities. *J. Appl. Meteorol.* **1980**, *19*, 819–825.
31. Koeppl, G.W. *Putnam's Power from the Wind*, 2nd ed.; Van Nostrand Reinhold: New York, NY, USA, 1982.
32. Ozerdem, B.; Turkeli, M. An investigation of wind characteristics on the campus of Izmir Institute of Technology, Turkey. *Renew. Energy* **2003**, *28*, 1013–1027.
33. Shata, A.S.A.; Hanitsch, R. Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt. *Renew. Energy* **2006**, *31*, 1183–1202.
34. Ramı´rez, P.; Carta, J.A. The use of wind probability distributions derived from the maximum entropy principle in the analysis of wind energy: a case study. *Energy Convers. Manag.* **2006**, *47*, 2564–2577.
35. Akpinar, S.; Akpinar, E.K. Wind energy analysis based on maximum entropy principle (MEP)-type distribution function. *Energy Convers. Manag.* **2007**, *48*, 1140–1149.
36. Tar, K. Some statistical characteristics of monthly average wind speed at various heights. *Renew. Sustain. Energy Rev.* **2007**, *12*, 1712–1724.
37. Chang, T.J.; Tu, Y.L. Evaluation of monthly capacity factor of WECS using chronological and probabilistic wind speed data: A case study of Taiwan. *Renew. Energy* **2007**, *32*, 1999–2010.
38. Shamilov, A.; Kantar, Y.M.; Usta, I. Use of MinMaxEnt distributions defined on basis of MaxEnt method in wind power study. *Energy Convers. Manag.* **2008**, *49*, 660–677.
39. Carta, J.A.; Ramírez, P.; Velázquez, S. A review of wind speed probability distributions used in wind energy analysis: Case studies in the Canary Islands. *Renew. Sustain. Energy Rev.* **2009**, *13*, 933–955.
40. Akpinar, E.K.; Akpinar, S. A statistical analysis of wind speed data used in installation of wind energy conversion systems. *Energy Convers. Manag.* **2005**, *46*, 515–532.
41. Akpinar, E.K.; Akpinar, S. An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics. *Energy Convers. Manag.* **2005**, *46*, 1848–1867.

42. Yang, G.; Du, Y.; Chen, M. Computer aided investigation towards the wind power generation potentials of Guangzhou. *Comput. Inform. Sci.* **2008**, *1*, 13–19.
43. Kamau, J.N.; Kinyua, R.; Gathua, J.K. 6 years of wind data for Marsabit, Kenya average over 14 m/s at 100 m hub height: An analysis of the wind energy potential. *Renew. Energy* **2010**, *35*, 1298–1302.
44. Chang, T.P. Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application. *Appl. Energy* **2011**, *88*, 272–282.
45. Akdag, S.A.; Bagiorgas, H.S.; Mihalakakou, G. Use of two-component Weibull mixtures in the analysis of wind speed in the Eastern Mediterranean. *Appl. Energy* **2010**, *87*, 2566–2573.
46. Chang, T.P.; Ko, H.; Liu, F.; Chen, P.; Chang, Y.; Liang, Y.; Jang, H.; Lin, T.; Chen, Y. Fractal dimension of wind speed time series. *Appl. Energy* **2012**, *93*, 742–749.
47. Qin, Z.; Li, W.; Xiong, X. Estimating wind speed probability distribution using kernel density method. *Electr. Power Syst. Res.* **2011**, *81*, 2139–2146.
48. Burton, T.; Sharpe, D.; Jenkins, N.; Bossanyi, E. *Wind Energy Handbook*; Wiley: Hoboken, NJ, USA, 2001.
49. Kose, R.; Ozgur, M.A.; Oguzhan Erbas, A.T. The analysis of wind data and wind energy potential in Kutahya, Turkey. *Renew. Sustain. Energy Rev.* **2004**, *8*, 277–288.
50. Kwon, S.D. Uncertainty analysis of wind energy potential assessment, *J. Appl. Energy* **2010**, *87*, 856–865.
51. Mohandes, M.; Rehman, S.; Rahman, S.M. Estimation of wind speed profile using adaptive neuro-fuzzy system (AFIS). *Appl. Energy* **2011**, *88*, 4024–4032.
52. Carta, J.A.; Ramirez, P.; Bueno, C.A. Joint probability density function of wind speed and direction for wind energy analysis. *Energy Convers. Manag.* **2008**, *49*, 1309–1320.
53. Carta, J.A.; Ramirez, P.; Velazquaz, S. Influence of the level of fit of a density probability function to wind speed data on the WECS mean power output estimation. *Energy Convers. Manag.* **2008**, *49*, 2647–2655.
54. Kollu, R.; Rayapudi, S.R.; Narasimham, S.V.L.; Pakkurthi, K.M. Mixture probabibility distribution for model wind speed distributions. *Int. J. Energy Environ. Eng.* **2012**, *3*, doi:10.1186/2251-6832-3-27.
55. Califf, R.; Emilion, R.; Soabdhan, T. Classification of wind speed distributions using a mixture of Dirichlel distribution. *Renew. Energy* **2011**, *36*, 3091–3097.
56. Carta, J.A.; Velazquaz, S. A new probability method to estimate the long-term wind speed characteristics at a potential wind energy conversion site. *Energy* **2011**, *36*, 2671–2685.
57. Liu, H.; Tian, H.; Li, Y. Comparison of two new ARIMA-ANN and ARIMA-Kalman hybrid methods for wind speed prediction. *Appl. Energy* **2012**, *98*, 415–424.
58. Ohijeagbon, O.D.; Ajayi, O.O. Potential and economic viability of stand-alone hybrid systems for a rural community of Sokoto, North-West Nigeria. *Front. Energy* **2014**, *8*, 145–159.
59. Montgomery, D.C.; Runger, G.C. *Applied Statistics and Probability for Engineers*, 3rd ed.; Wiley: Hoboken, NJ, USA, 2003.
60. Keyhani, A.; Ghasemi-Varnamkhasti, M.; Khanali, M.; Abbaszadeh, R. An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. *Energy* **2010**, *35*, 188–201.

61. Ajayi, O.O.; Fagbenle, R.O.; Katende, J.; Aasa, S.A.; Okeniyi, J.O. Wind profile characteristics and turbine performance analysis in Kano, North-Western Nigeria. *Int. J. Energy Environ. Eng.* **2013**, *4*, doi:10.1186/2251-6832-4-27.
62. GE Energy. 1.5 MW wind turbine. Available online: http://www.ge-energy.com/prod_serv/products/wind_turbines/en/downloads/GEA14954C15-MW-Broch.pdf (accessed on 29 September 2010).
63. Central Bank of Nigeria (CBN). Economic indicators. Available online: http://www.cenbank.org (accessed on 27 April 2013).